ILLINOIS STATE WATER SURVEY

Meteorologic Laboratory

at the

University of Illinois

Urbana, Illinois

# INVESTIGATION OF THE QUANTITATIVE DETERMINATION OF POINT AND AREAL PRECIPITATION BY RADAR ECHO MEASUREMENTS

Sixth Quarterly Technical Report

1 January 1963 - 31 March 1963



Sponsored by
U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey

CONTRACT NO. DA-36-039 SC-87280
DA Task 3A99-07-001-01

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AD ______ Accession No. ______
Illinois State Water Survey Division, Urbana, Illinois. INVESTIGATION OF THE QUANTITATIVE DETERMINATION OF POINT AND AREAL PRECIPITATION BY RADAR ECHO MEASUREMENTS - E. A. Mueller

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Results of stratifying drop size data from Majuro with respect to height of the condensation level are presented. These indicate that there are significant differences in the distribution. The explanation of these differences is not clear.

An example of a time sequence of drop size data obtained at Mt. Withington, New Mexico, is presented.

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3. Coalescence Theory
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# INVESTIGATION OF THE QUANTITATIVE DETERMINATION OF POINT AND AREAL PRECIPITATION BY RADAR ECHO MEASUREMENTS

SIXTH QUARTERLY TECHNICAL REPORT

1 January 1963 - 31 March 1963

Signal Corps Contract: DA-36-039 SC-87280

DA Task 3A99-07-001-01

Sponsored by

U. S. Army
Signal Research and Development Laboratory
Fort Monmouth, New Jersey

To record and analyze data on raindrop-size distribution in various parts of the world. These data will be correlated with appropriate radar parameters in order to improve the capability of radar in measuring surface rainfall intensities for Army applications such as radioactive rainout prediction, trafficability, and communications.

Prepared by

E. A. Mueller
Project Engineer

G. E. Stout
Project Director

William C. Ackermann, Chief
Illinois State Water Survey

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## PURPOSE

The object of this research is to study the utility of radar equipment in measuring surface precipitation and to improve radar techniques in measuring precipitation for application by the Army to radioactive rainout prediction, trafficability, and communications. Considerable effort is being directed toward determining the correlation between radar variables and actual rainfall quantities by means of raindrop-size distribution.

## ABSTRACT

During the past quarter the raindrop cameras were reinstalled at locations A and B on the East Central Illinois Raingage Network. The third camera will be installed during the coming month as soon as the 30-inch parabolic mirror is returned from resurfacing.

Processing of raindrop camera data has been continued in a routine manner. The preliminary computations on the raindrop data are up to date.

The results of stratifying the data with respect to the condensation level, determined by the radiosonde, has been completed. The results indicate that there is a significant difference in the drop size distributions from the high condensation levels as compared to the low condensation levels for low precipitation rates. At moderate to strong rainfall rates, the difference in the distributions becomes considerably less apparent. Estimations of the

effect of evaporation on the drop size distributions cannot explain the differences in the drop size distributions that are obtained.

Some of the results from the cooperative experiments with Arthur D. Little, Inc., at Mt. Withington, New Mexico, are presented. The rainfall rates as calculated from the drop size distributions agree very well with the rainfall rates as recorded by a raingage with the exception of one sample of 104 mm per hour at which time light hail was falling. The hail gush may have been associated with a lightning stroke. The form of the curve at this time suggests that the coalescence process was active for the water drops.

## PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

On January 15, 1963, Mr. G. E. Stout and Mr. E. A. Mueller visited Evans Laboratory at Belmar, New Jersey, where plans for the coming data collection period were discussed. It was decided to move one drop camera to Flagstaff, Arizona, during the summer of 1963. Dr. Vincent Schaefer will be asked if he can provide an operator for this installation.

Research Report No. 8, entitled "Raindrop Size Distributions with Rainfall Types and Weather Conditions," was distributed.

## RADAR OPERATIONAL PROGRAM

### CPS-9

The CPS-9 radar has been placed in routine operation. The new wave-guide pressurizing system is working very satisfactorily and since it has been installed there has been no difficulty with this portion of the radar. Some difficulties have been experienced with the vertical drive system for the radar antenna. This drive system is a "Hybrid," most of which was obtained from an old SCR-545 radar. The antenna tracking in the vertical has shown some erratic operations and further work will be necessary before reliable quasi-CAPI operations can be performed.

TPS-10

The TPS-10 radar has not been put into operation as yet. Considerable difficulties have been experienced with the azimuth drive system for the TPS-10 radar and also some difficulties in the transmitter receiver. These problems are being worked upon and the TPS-10 radar should be operational within the next month. A second camera is being installed on the TPS-10 radar to allow an option of 16-mm pictures or 35-mm pictures or both. The addition of a 16-mm camera will allow continuous data collection without the film cost becoming exorbitant.

## RAINDROP CAMERAS

The raindrop cameras at the two northernmost locations have been installed and are operating. These two cameras are connected together by means of field wire so that both cameras operate with one automatic rain switch. Very little difficulty was experienced in reinstalling these cameras. Only two days were required to install, realign, and readjust the focusing on these two cameras.

Test pictures have been obtained and the cameras are in good condition for the coming data collection period. The third camera has not been installed due to a slow delivery of the resurfaced mirror from the resurfacing company in Chicago. As soon as this mirror is returned the third camera will be installed. If possible, this camera will also be connected to the existing rain switch at camera A to allow all three cameras to be turned on simultaneously. The field cable necessary for this third camera will have to traverse a long path of greater than a mile and a half. Part of this distance will be along fence rows which should be protected from breakage but a portion of it will have to be run alongside an open field. This section of the wire may be easily damaged by farm equipment and grass mowers. If it turns out that it is too unreliable to connect the third camera, a second rain switch will be placed at the third camera for turning this camera on.

The desired data collection program for the three cameras will consist of running the cameras with concurrent radar observations of the immediate area with both the CPS-9 and TPS-10 radars. A careful analysis of the radar data will then determine the portion of the echo or the storm complex which is contributing to each of the drop size at each of the cameras. In this way, it is hoped that effects due to throwout of large drops from the tops of storms or the effects of wind shear on the drop size distribution can be assessed. Rainfall rate-radar reflectivity relationships will be determined from the three cameras separately to obtain a measure of how reliable a single camera's R-Z relationship is for a particular storm. It is hoped that R-Z relationships as determined from the single storm from each of the three cameras will be very nearly the same.

## DATA ANALYSIS

### Raindrop Data Reduction

During the quarter a total of 17 rolls of raindrop data has been measured. Eleven of these rolls represent data from Island Beach, New Jersey, and 6 of these rolls represent data from Coweeta, North Carolina. As data are obtained on the East Central Illinois Raingage Network, they will be measured in preference to continued measurements at these two locations, since it will be desirable to determine as soon as possible whether a sufficiency of drop size data from the East Central Illinois Raingage Network has been obtained.

The data that have been measured are being processed by the computers and the back-log of computer data which was built up during the switch over of computers has all been processed. Therefore, at this time, the data are being processed as rapidly as read from the film.

### Effect of Condensation Level on Drop Size Distribution

Additional work of a previously reported pilot study to determine the differences in drop size data from clouds with different condensation levels shows that the results obtained in the pilot study were, in general, fairly representative. All of the data from Majuro was stratified according to the condensation level as determined by the preceding radiosonde data. Stratification was in 9 levels. Level 1 represented condensation height less than 450 feet. Levels 2 through 7 were consecutive 200-foot height intervals to 1600 feet. Level 8 was 1600 feet to 2000 feet and level 9 greater than 2000 feet. Average raindrop size distributions were then computed for each of the levels. Figures 1, 2, and 3 show the results for low, moderate, and heavy rainfall rates. For all rates less than 10 millimeters per hour the drop size distributions for the higher condensation levels showed a much narrower distribution with a larger total number of drops. A number of possible causes may be responsible for these differences, among these are: different basic rain formation mechanism, evaporation after leaving cloud, coalescence after leaving cloud, or drop break up.

Effects of evaporation have been investigated. It would seem that there is little possibility for evaporation to be the responsible agent for the differences in distributions.

According to Johnson[1], the size of a raindrop after undergoing evaporation can be expressed by:

$$a^2 = a_o^2 + 8\,\frac{K}{D}(\rho_W - \rho_{OW})t \qquad (1)$$

where a is the final radius

$a_o$ is the starting radius

K is the diffusivity

$\rho_w$ is the concentration of water vapor

$\rho_{ow}$ is the saturated water vapor density at the temperature of the drop surface

D is the density of liquid water

t is the time.

Since we are considering evaporation, the entire second term will be negative. If it is assumed that all drops are at the same temperature, the coefficient of t will be the same for all drops. The length of time that evaporation can be active will vary inversely with the drop velocities and since to the first approximation velocity varies as the 1/2 power of diameter, Eq. (1) can be written

$$a^2 = a_o{}^2 - \frac{A}{\sqrt{a}} h$$

where A is a constant determined by humidity, diffusivity and the relationship between velocity and diameter of the drop, and h is the height of fall.

Application of this equation to drop size distribution produces a broadening of the overall distribution. The effect on the radius of small drops is much more apparent than the effect on the radius of large drops. This is in general agreement with the results of Imai[2] using Kinzer & Gunn[3] data. Therefore, if evaporation is to account for the differences in distribution, evaporation must be more active with the low condensation level. This appears to be untrue and therefore it is believed that the differences in distributions from the different condensation levels are not due to evaporation.

It is also difficult to attribute the effect to coalescence, even though coalescence produces the narrow distribution, since this process tends to reduce the number of drops per cubic meter as the process continues. Therefore, if coalescence from cloud base to ground is the agent for producing these differences, the distribution at the base of the cloud must have been a very large number of much smaller drops than the final distribution. It is also significant that these effects are much stronger in low rainfall rate regions. This would seem to favor effects of evaporation and due to the reduced concentration of drops reduces coalescence rate.

The effect of drop break up appears to be an attractive alternative to explain these distributions. If it is considered that a drop of 1.2 mm broke into three equally sized drops, these would result in 3 drops of 0.8 mm in diameter. This process would then tend to account for the larger total number of drops and also the mode shift toward the smaller sizes. As to the reason the effect is stronger in the small rates, it could only be assumed that the turbulence below the cloud base was more violent.

Exact interpretation of this data is extremely difficult and further effort will be expended in trying to better assess the effects of evaporation and coalescence in producing this sort of differences in the drop size distributions.

Drop Size Distributions from Mt. Withington, New Mexico

All of the data from Mt. Withington, New Mexico, from the year 1962 have been measured and computations performed. The results have been exchanged with Arthur D. Little, Inc., personnel who were operating the majority of the experimental work on the mountain. We are indebted to C. B. Moore and B. V. Vonnegut for use of Figure 4 in this report. Figure 4 represents the rainfall rate as obtained from the tipping bucket raingage which was operated by ADL on the mountain as well as the rainfall rate as obtained from the raindrop camera. The timing of the tipping bucket was within .2 of a second; therefore, the calculated values of rainfall rate are reasonably accurate. The drop size distribution rates as can be seen by Figure 4 compare quite well with the rainfall rates as determined from the tipping bucket except for the single observation at 1301. At this time there was soft hail in evidence in the drop camera pictures. The observer on the mountain logged a hail shaft arriving at the radar at 1301. The drop camera was 1/2-minute behind this observation in its next data picture. There was a very little hail in evidence on the 1300:30 pictures. The drop size distribution for the minute 1301:30 is shown in Figure 5. The largest hail stone in the distribution was 5.4 millimeters in diameter. It can be noted that the number of drops in the distribution was only 827 per cubic meter which was not greatly different than the two minutes previously which had 717 and 903 drops, respectively. Likewise, the following minute had only 438 drops in it. Therefore, the changes that were taking place during this time were in the diameters in both the generation and the tailing off period. In general, the number of drops did not change rapidly but the number of large drops did exhibit a large change. The minute prior had only 1 drop greater than 3.7 millimeters and the minute 1301:30 had 20 drops greater than 3.7 millimeters. This rapid increase in number of hail drops contributed to the high rainfall rate calculated and also to the high value of Z calculated. The Z for this minute was $2.4 \times 10^5$ where the previous minute was only $7.2 \times 10^4$. This represents an increase of 5 db per minute in the Z value. Much higher values of Z changes per minute were recorded by the radar on top of the mountain. An equally interesting sequence of drop size distributions were obtained around the period of 1254:30 to 1256:30. During this time, also following a lightning stroke, a very rapid increase in the Z values was obtained. Between 1251:30 and 1253:30, a Z change of nearly 10 db per minute was noted on the drop camera data. A much higher Z change was determined at this time from the radar (in excess of 3 db per second). These data seem to indicate that some process at times is responsible for a very rapid change in the number and size of raindrops that are measured at the ground as well as the radar back-scattering cross-section Z. It remains to be determined whether these rapid changes in Z and rainfall rate can be attributed to electrical effects occurring immediately after the lightning strokes. It can be noted on Figure 4 that the vertical lines extended upward from the center horizontal line are times when the lightning detector on top of the mountain indicated that there was some lightning in the vicinity. It is possible that some of the negative lightning strokes indicated may have been reflections of the positive strokes just prior to the negative ones. The timing of these lightning strokes was also to the nearest .2 of a second. Some of the lightning strokes were noted by observers and the observers' comments are written on the figure. In particular, it is interesting to note the lightning that struck the ground approximately 100 meters north just prior to the arrival of the hail shafted the ground and it is interesting to speculate whether this lightning in any way influenced the formation of the hail which appeared at 1301:30.

## SUMMARY AND CONCLUSIONS

Data processing is continuing on a routine basis with scheduled progress being made. The raindrop cameras have been reinstalled for a summer's data collection period and the radars are either operative or will be operative in the near future.

It is apparent that there are striking differences in drop size distribution depending upon the condensation level from which the rain fell and the exact explanation of these differences has not been determined. More effort will be expended in attempting to explain these differences in terms of physical processes as well as fit these curves by the standard coalescence curves. After the coalescence curves have been fit to the distributions, attempts will be made to correlate the coalescence parameters with the physical parameters.

## PERSONNEL

The following personnel were engaged in the research during the sixth quarter:

| Name and Title | Starting Date | Hours Worked | Terminated |
|---|---|---|---|
| G. E. Stout<br>Project Director | 10/1/61 | 60 | |
| Eugene A. Mueller<br>Electronic Engineer | 10/1/61 | 476 | |
| Edna M. Anderson<br>Meteorological Aide I | 10/1/61 | 510 | |
| Dorothy A. Tew (Gurney)<br>Meteorological Aide I | 10/1/61 | 510 | |
| Charles F. Medrow<br>Electronics Technician | 10/1/61 | 288 | 3/8/63 |
| Marian E. Adair<br>Meteorological Aide I | 9/24/62 | 243 | |
| Ileah W. Trover<br>Meteorological Aide I | 9/10/62 | 387 | |
| Margaret A. Coy<br>Laboratory Assistant | 9/4/62 | 34 | 1/29/63 |
| Ruth V. Eadie<br>Meteorological Aide I | 11/31/61 | 510 | |
| Ronald G. Custer<br>Scientific Assistant | 10/15/62 | 2 | 1/15/63 |
| Gerald W. Swanson<br>Statistical Clerk | 10/31/62 | 155 | |
| Nazir Ansari<br>Statistical Clerk | 10/1/61 | 200 | |

| Name and Title | Starting Date | Hours Worked | Terminated |
|---|---|---|---|
| Stanley G. Peery<br>Electronics Technician II | 3/1/63 | 170 | |
| Victor C. Munson<br>Electronics Technician I | 3/11/63 | 120 | |

## REFERENCES


1. Johnson, J. C., Physical Meteorology, John Wiley & Sons, 1954, p. 215.

2. Imai, I., "Raindrop Size Distributions and Z-R Relationship," Proceedings of Eighth Weather Radar Conference, 1960.

3. Kinzer, G. D. and R. Gunn, "The Evaporation, Temperature and Thermal Relaxation - Time of Freely Falling Waterdrops," J. of Met., V. 8, No. 2, 1951, pp. 71-83.

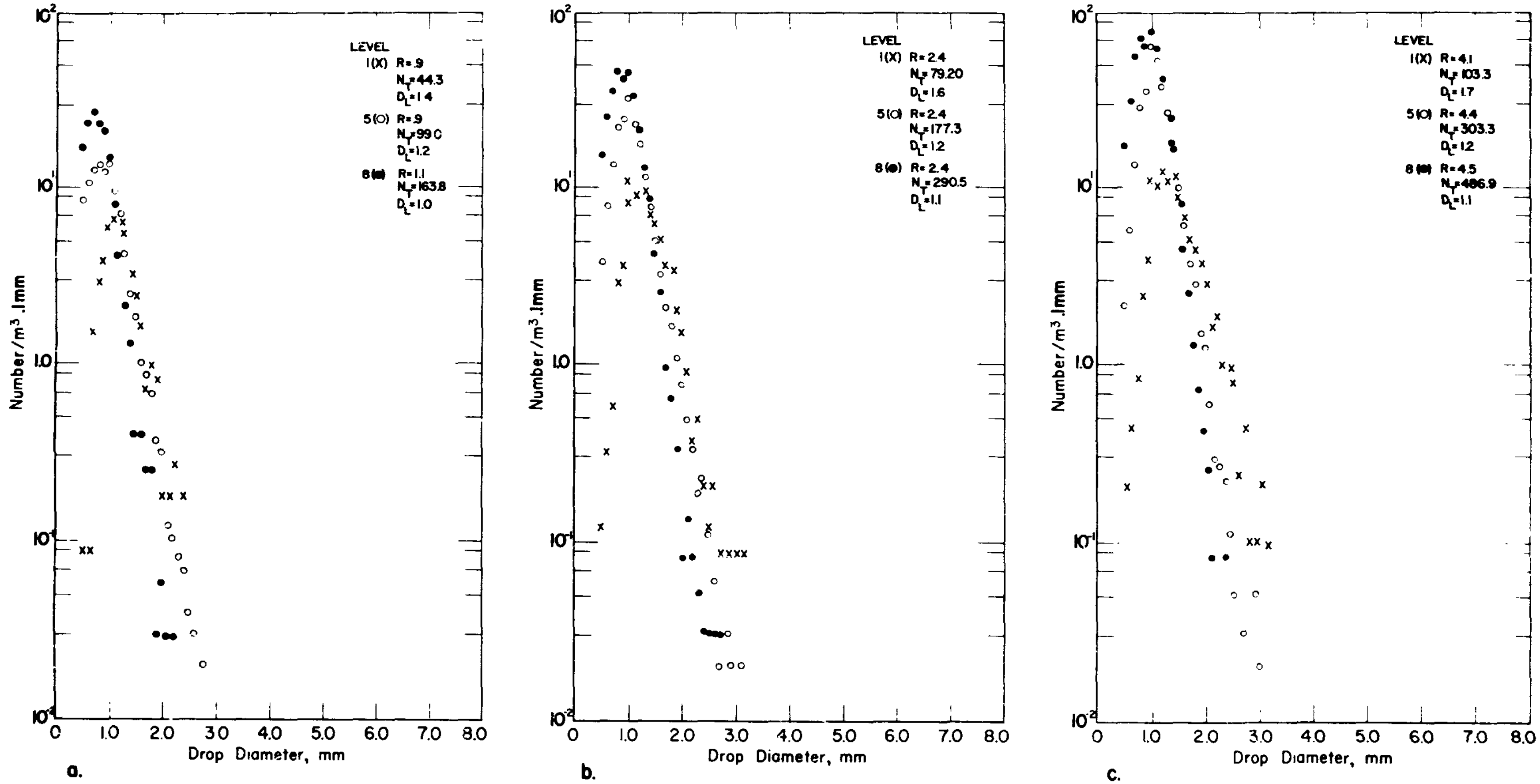


FIG. 1 COMPARISON OF DROP SIZE DISTRIBUTIONS FOR DIFFERENT CONDENSATION LEVELS AND LOW RAINFALL RATES FROM MAJURO.

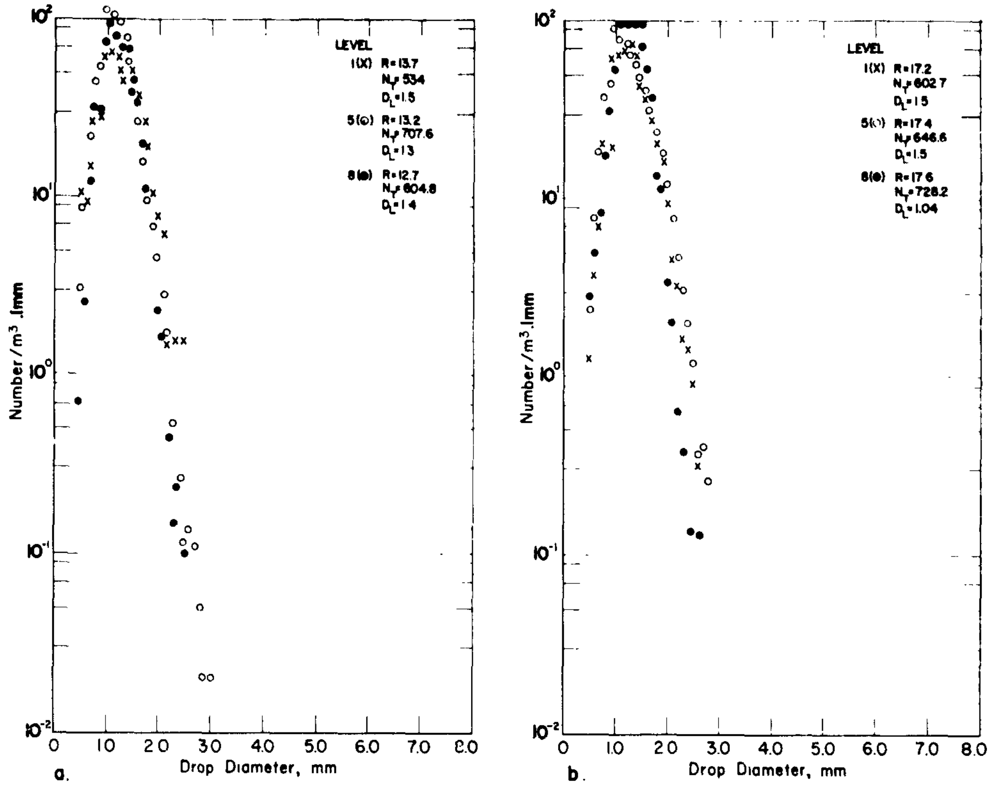


FIG. 2 COMPARISON OF DROP SIZE DISTRIBUTIONS FOR DIFFERENT CONDENSATION LEVELS AND MODERATE RAINFALL RATES FROM MAJURO

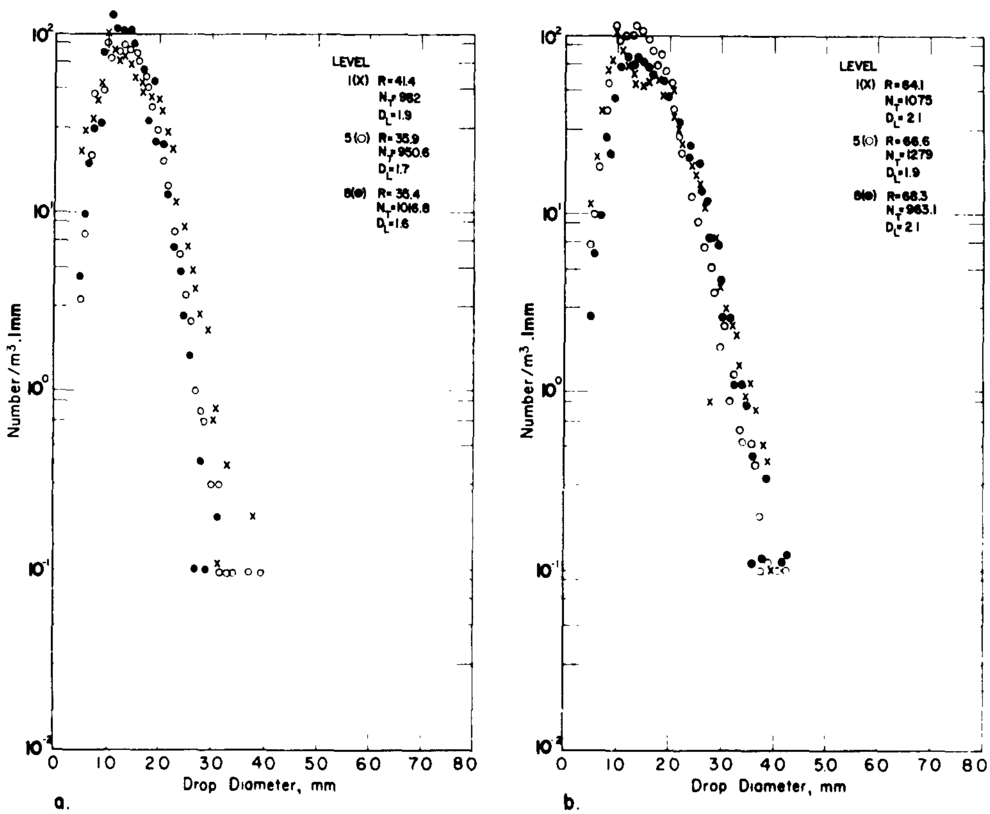


FIG. 3 COMPARISON OF DROP SIZE DISTRIBUTIONS FOR DIFFERENT CONDENSATION LEVELS AND HIGH RAINFALL RATES FROM MAJURO

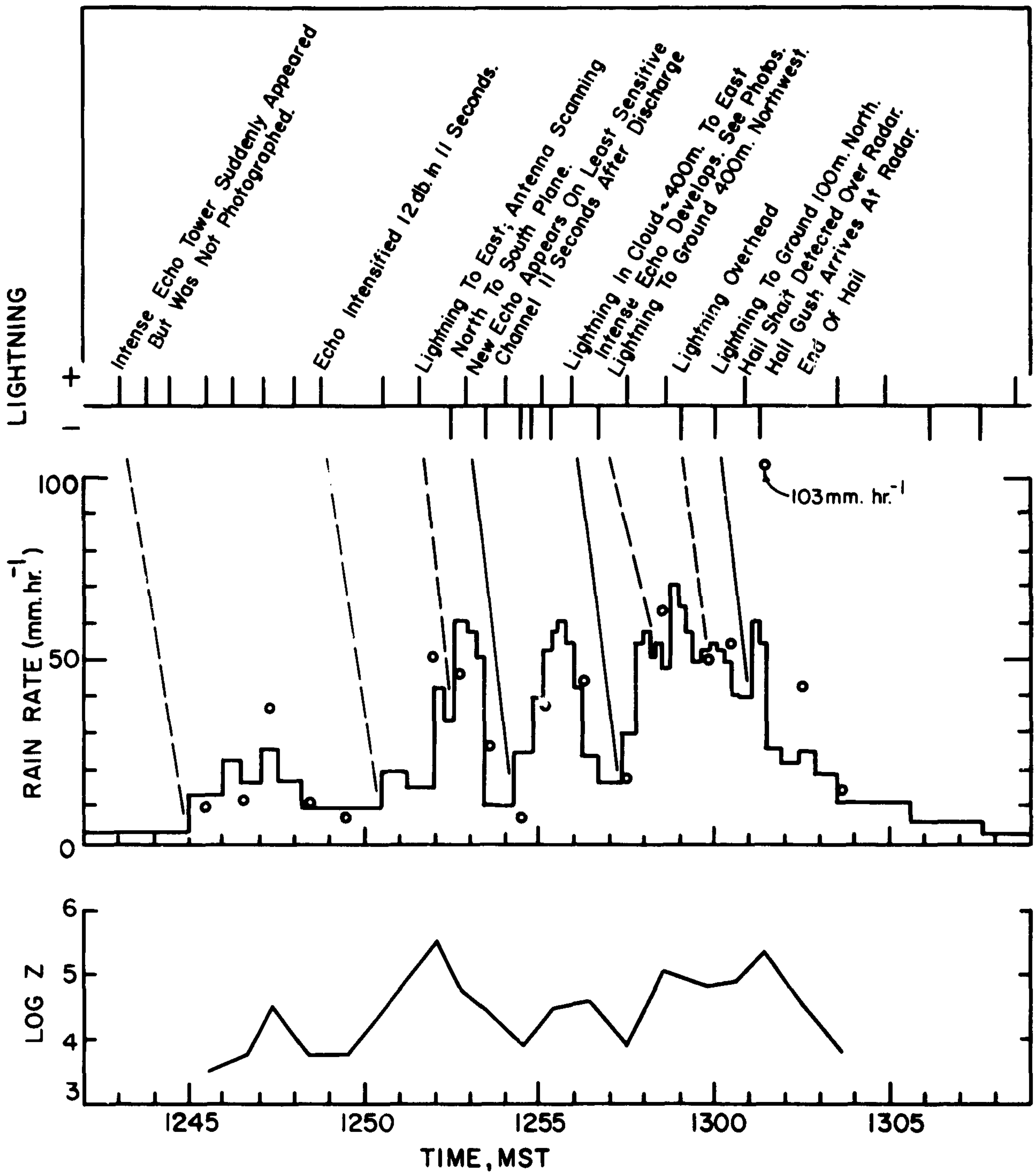


FIG. 4 TIME PLOT OF DROP SIZE DATA FOR JULY 30, 1962 AT MT. WITHINGTON

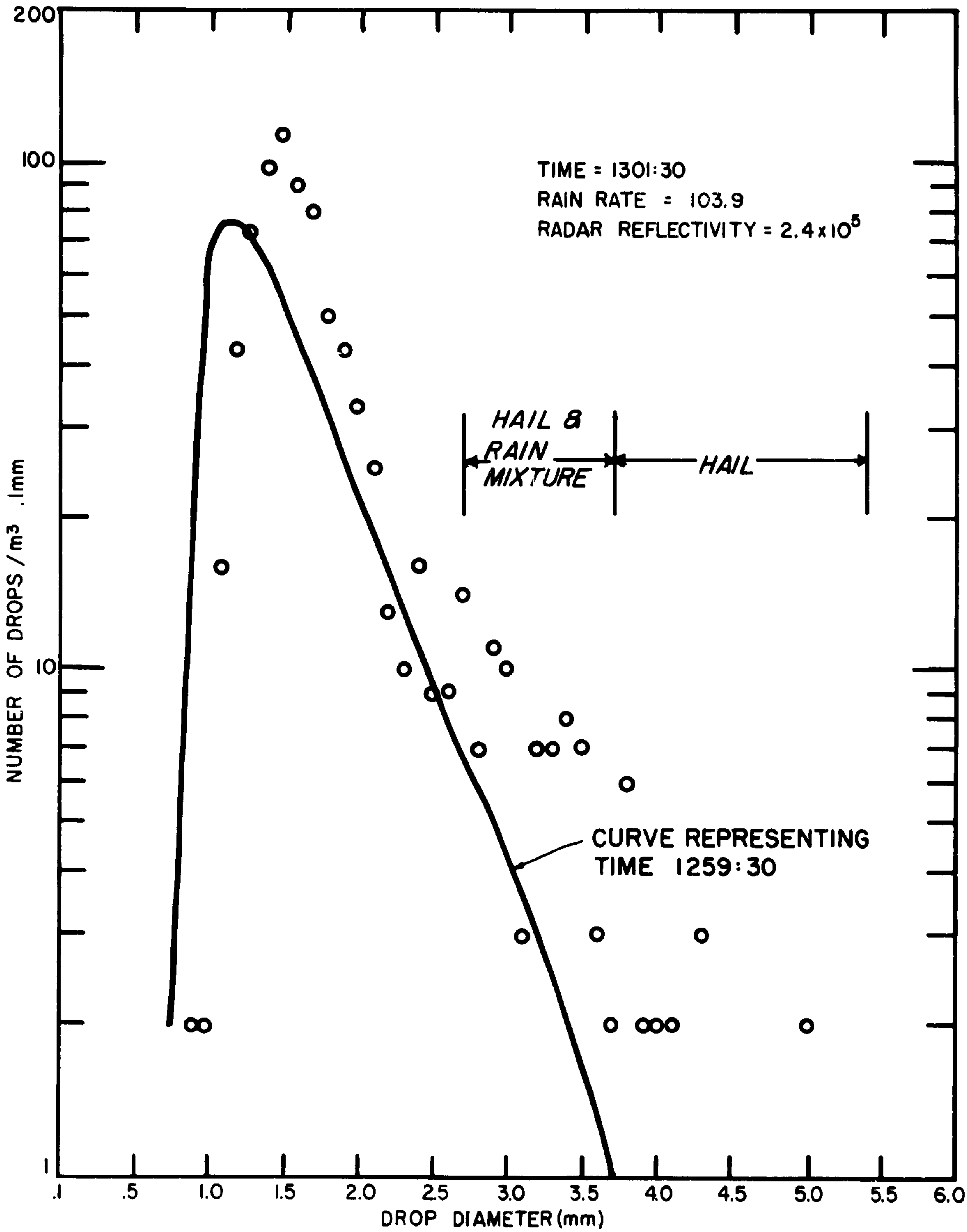


FIG. 5 DROP SIZE DISTRIBUTION FOR JULY 30, 1962, 1301:30 MST, FROM MT. WITHINGTON

U. S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY
METEOROLOGICAL TECHNIQUES BRANCH
BELMAR, NEW JERSEY

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